

Interference Cancellation in Non-coherent CDMA Systems Using Parallel Iterative Algorithms

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Abstract—Parallel least mean square-partial parallel interference cancellation (PLMS-PPIC) is a partial interference cancellation which employs adaptive multistage structure [1]. In this algorithm the channel phases for all users are assumed to be known. Having only their quarters in $(0, 2\pi)$, a modified version of PLMS-PPIC is proposed in this paper to simultaneously estimate the channel phases and the cancellation weights. Simulation examples are given in the cases of balanced, unbalanced and time varying channels to show the performance of the modified PLMS-PPIC method.

I. INTRODUCTION

The multiple access interferences (MAI) is the root of user limitation in CDMA systems [2], [5]. The parallel least mean square-partial parallel interference cancellation (PLMS-PPIC) method is a multiuser detector for code division multiple access (CDMA) receivers which reduces the effect of MAI in bit detection. In this method and similar to its former versions like LMS-PPIC [6] (see also [7]), a weighted value of the MAI of other users is subtracted before making the decision for a specific user in different stages [1]. In both of these methods, the normalized least mean square (NLMS) algorithm is engaged [8]. The m^{th} element of the weight vector in each stage is the true transmitted binary value of the m^{th} user divided by its hard estimate value from the previous stage. The magnitude of all weight elements in all stages are equal to unity. Unlike the LMS-PPIC, the PLMS-PPIC method tries to keep this property in each iteration by using a set of NLMS algorithms with different step-sizes instead of one NLMS algorithm used in LMS-PPIC. In each iteration, the parameter estimate of the NLMS algorithm is chosen whose element magnitudes of cancellation weight estimate have the best match with unity. In PLMS-PPIC implementation it is assumed that the receiver knows the phases of all user channels. However in practice, these phases are not known and should be estimated. In this paper we improve the PLMS-PPIC procedure [1] in such a way that when there is only a partial information of the channel phases, this modified version simultaneously estimates the phases and the cancellation weights. The partial information is the quarter of each channel phase in $(0, 2\pi)$.

The rest of the paper is organized as follows: In section II the modified version of PLMS-PPIC with capability of channel phase estimation is introduced. In section III some simulation

examples illustrate the results of the proposed method. Finally the paper is concluded in section IV.

II. MULTISTAGE PARALLEL INTERFERENCE CANCELATION: MODIFIED PLMS-PPIC METHOD

We assume M users synchronously send their symbols $\alpha_1, \alpha_2, \dots, \alpha_M$ via a base-band CDMA transmission system where $\alpha_m \in \{-1, 1\}$. The m^{th} user has its own code $p_m(\cdot)$ of length N , where $p_m(n) \in \{-1, 1\}$, for all n . It means that for each symbol N bits are transmitted by each user and the processing gain is equal to N . At the receiver we assume that perfect power control scheme is applied. Without loss of generality, we also assume that the power gains of all channels are equal to unity and users' channels do not change during each symbol transmission (it can change from one symbol transmission to the next one) and the channel phase ϕ_m of m^{th} user is unknown for all $m = 1, 2, \dots, M$ (see [1] for coherent transmission). According to the above assumptions the received signal is

$$r(n) = \sum_{m=1}^M \alpha_m e^{j\phi_m} p_m(n) + v(n), \quad n = 1, 2, \dots, N, \quad (1)$$

where $v(n)$ is the additive white Gaussian noise with zero mean and variance σ^2 . Multistage parallel interference cancellation method uses $\alpha_1^{s-1}, \alpha_2^{s-1}, \dots, \alpha_M^{s-1}$, the bit estimates outputs of the previous stage, $s-1$, to estimate the related MAI of each user. It then subtracts it from the received signal $r(n)$ and makes a new decision on each user variable individually to make a new variable set $\alpha_1^s, \alpha_2^s, \dots, \alpha_M^s$ for the current stage s . Usually the variable set of the first stage (stage 0) is the output of a conventional detector. The output of the last stage is considered as the final estimate of transmitted bits. In the following we explain the structure of a modified version of the PLMS-PIC method [1] with simultaneous capability of estimating the cancellation weights and the channel phases.

Assume $\alpha_m^{(s-1)} \in \{-1, 1\}$ is a given estimate of α_m from stage $s-1$. Define

$$w_m^s = \frac{\alpha_m}{\alpha_m^{(s-1)}} e^{j\phi_m}. \quad (2)$$

From (1) and (2) we have

$$r(n) = \sum_{m=1}^M w_m^s \alpha_m^{(s-1)} p_m(n) + v(n). \quad (3)$$

Define

$$W^s = [w_1^s, w_2^s, \dots, w_M^s]^T, \quad (4a)$$

$$X^s(n) = [\alpha_1^{(s-1)} p_1(n), \alpha_2^{(s-1)} p_2(n), \dots, \alpha_M^{(s-1)} p_M(n)]^T \quad (4b)$$

where T stands for transposition. From equations (3), (4a) and (4b), we have

$$r(n) = W^{sT} X^s(n) + v(n). \quad (5)$$

Given the observations $\{r(n), X^s(n)\}_{n=1}^N$, in modified PLMS-PPIC, like the PLMS-PPIC [1], a set of NLMS adaptive algorithm are used to compute

$$W^s(N) = [w_1^s(N), w_2^s(N), \dots, w_M^s(N)]^T, \quad (6)$$

which is an estimate of W^s after iteration N . To do so, from (2), we have

$$|w_m^s| = 1 \quad m = 1, 2, \dots, M, \quad (7)$$

which is equivalent to

$$\sum_{m=1}^M ||w_m^s| - 1| = 0. \quad (8)$$

We divide $\Psi = (0, 1 - \sqrt{\frac{M-1}{M}}]$, a sharp range for μ (the step-size of the NLMS algorithm) given in [9], into L subintervals and consider L individual step-sizes $\Theta = \{\mu_1, \mu_2, \dots, \mu_L\}$, where $\mu_1 = \frac{1 - \sqrt{\frac{M-1}{M}}}{L}$, $\mu_2 = 2\mu_1, \dots$, and $\mu_L = L\mu_1$. In each stage, L individual NLMS algorithms are executed (μ_l is the step-size of the l^{th} algorithm). In stage s and at iteration n , if $W_k^s(n) = [w_{1,k}^s, \dots, w_{M,k}^s]^T$, the parameter estimate of the k^{th} algorithm, minimizes our criteria, then it is considered as the parameter estimate at time iteration n . In other words if the next equation holds

$$W_k^s(n) = \arg \min_{W_l^s(n) \in I_{W^s}} \left\{ \sum_{m=1}^M ||w_{m,l}^s(n)| - 1| \right\}, \quad (9)$$

where $W_l^s(n) = W^s(n-1) + \mu_l \frac{X^s(n)}{\|X^s(n)\|^2} e(n)$, $l = 1, 2, \dots, k, \dots, L-1, L$ and $I_{W^s} = \{W_1^s(n), \dots, W_L^s(n)\}$, then we have $W^s(n) = W_k^s(n)$, and therefore all other algorithms replace their weight estimate by $W_k^s(n)$. At time instant $n = N$, this procedure gives $W^s(N)$, the final estimate of W^s , as the true parameter of stage s .

Now consider $R = (0, 2\pi)$ and divide it into four equal parts $R_1 = (0, \frac{\pi}{2})$, $R_2 = (\frac{\pi}{2}, \pi)$, $R_3 = (\pi, \frac{3\pi}{2})$ and $R_4 = (\frac{3\pi}{2}, 2\pi)$. The partial information of channel phases (given by the receiver) is in a way that it shows each ϕ_m ($m = 1, 2, \dots, M$) belongs to which one of the four quarters R_i , $i = 1, 2, 3, 4$. Assume $W^s(N) = [w_1^s(N), w_2^s(N), \dots, w_M^s(N)]^T$ is the

weight estimate of the modified algorithm PLMS-PPIC at time instant N of the stage s . From equation (2) we have

$$\phi_m = \angle \left(\frac{\alpha_m^{(s-1)}}{\alpha_m} w_m^s \right). \quad (10)$$

We estimate ϕ_m by $\hat{\phi}_m^s$, where

$$\hat{\phi}_m^s = \angle \left(\frac{\alpha_m^{(s-1)}}{\alpha_m} w_m^s(N) \right). \quad (11)$$

Because $\frac{\alpha_m^{(s-1)}}{\alpha_m} = 1$ or -1 , we have

$$\hat{\phi}_m^s = \begin{cases} \angle w_m^s(N) & \text{if } \frac{\alpha_m^{(s-1)}}{\alpha_m} = 1 \\ \pm\pi + \angle w_m^s(N) & \text{if } \frac{\alpha_m^{(s-1)}}{\alpha_m} = -1 \end{cases} \quad (12)$$

Hence $\hat{\phi}_m^s \in P^s = \{\angle w_m^s(N), \angle w_m^s(N) + \pi, \angle w_m^s(N) - \pi\}$. If $w_m^s(N)$ sufficiently converges to its true value w_m^s , the same region for $\hat{\phi}_m^s$ and ϕ_m is expected. In this case only one of the three members of P^s has the same region as ϕ_m . For example if $\phi_m \in (0, \frac{\pi}{2})$, then $\hat{\phi}_m^s \in (0, \frac{\pi}{2})$ and therefore only $\angle w_m^s(N)$ or $\angle w_m^s(N) + \pi$ or $\angle w_m^s(N) - \pi$ belongs to $(0, \frac{\pi}{2})$. If, for example, $\angle w_m^s(N) + \pi$ is such a member between all three members of P^s , it is the best candidate for phase estimation. In other words,

$$\phi_m \approx \hat{\phi}_m^s = \angle w_m^s(N) + \pi.$$

We admit that when there is a member of P^s in the quarter of ϕ_m , then $w_m^s(N)$ converges. What would happen when non of the members of P^s has the same quarter as ϕ_m ? This situation will happen when the absolute difference between $\angle w_m^s(N)$ and ϕ_m is greater than π . It means that $w_m^s(N)$ has not converged yet. In this case where we can not count on $w_m^s(N)$, the expected value is the optimum choice for the channel phase estimation, e.g. if $\phi_m \in (0, \frac{\pi}{2})$ then $\frac{\pi}{4}$ is the estimation of the channel phase ϕ_m , or if $\phi_m \in (\frac{\pi}{2}, \pi)$ then $\frac{3\pi}{4}$ is the estimation of the channel phase ϕ_m . The results of the above discussion are summarized in the next equation

$$\hat{\phi}_m^s = \begin{cases} \angle w_m^s(N) & \text{if } \angle w_m^s(N), \phi_m \in R_i, \quad i = 1, 2, 3, 4 \\ \angle w_m^s(N) + \pi & \text{if } \angle w_m^s(N) + \pi, \phi_m \in R_i, \quad i = 1, 2, 3, 4 \\ \angle w_m^s(N) - \pi & \text{if } \angle w_m^s(N) - \pi, \phi_m \in R_i, \quad i = 1, 2, 3, 4 \\ \frac{(i-1)\pi + i\pi}{4} & \text{if } \phi_m \in R_i, \quad \angle w_m^s(N), \angle w_m^s(N) \pm \pi \notin R_i \end{cases}$$

Having an estimation of the channel phases, the rest of the proposed method is given by estimating α_m^s as follows:

$$\alpha_m^s = \text{sign} \left\{ \text{real} \left\{ \sum_{n=1}^N q_m^s(n) e^{-j\hat{\phi}_m^s} p_m(n) \right\} \right\}, \quad (13)$$

where

$$q_m^s(n) = r(n) - \sum_{m'=1, m' \neq m}^M w_{m'}^s(N) \alpha_{m'}^{(s-1)} p_{m'}(n). \quad (14)$$

The inputs of the first stage $\{\alpha_m^0\}_{m=1}^M$ (needed for computing $X^1(n)$) are given by

$$\alpha_m^0 = \text{sign} \left\{ \text{real} \left\{ \sum_{n=1}^N r(n) e^{-j\hat{\phi}_m^0} p_m(n) \right\} \right\}. \quad (15)$$

TABLE I
CHANNEL PHASE ESTIMATE OF THE FIRST USER (EXAMPLE 1)

$\phi_n = \frac{3\pi}{8}, M = 15$	N(Iteration)	Stage Number	NLMS	PNLMS
	64	s = 2	$\hat{\phi}_m^s = \frac{3.24\pi}{8}$	$\hat{\phi}_m^s = \frac{3.18\pi}{8}$
		s = 3	$\hat{\phi}_m^s = \frac{3.24\pi}{8}$	$\hat{\phi}_m^s = \frac{3.18\pi}{8}$
	256	s = 2	$\hat{\phi}_m^s = \frac{2.85\pi}{8}$	$\hat{\phi}_m^s = \frac{2.88\pi}{8}$
		s = 3	$\hat{\phi}_m^s = \frac{2.85\pi}{8}$	$\hat{\phi}_m^s = \frac{2.88\pi}{8}$

Assuming $\phi_m \in R_i$, then

$$\hat{\phi}_m^0 = \frac{(i-1)\pi + i\pi}{4}. \quad (16)$$

Table III shows the structure of the modified PLMS-PPIC method. It is to be notified that

- Equation (15) shows the conventional bit detection method when the receiver only knows the quarter of channel phase in $(0, 2\pi)$.
- With $L = 1$ (i.e. only one NLMS algorithm), the modified PLMS-PPIC can be thought as a modified version of the LMS-PPIC method.

In the following section some examples are given to illustrate the effectiveness of the proposed method.

III. SIMULATIONS

In this section we have considered some simulation examples. Examples 1-3 compare the conventional, the modified LMS-PPIC and the modified PLMS-PPIC methods in three cases: balanced channels, unbalanced channels and time varying channels. In all examples, the receivers have only the quarter of each channel phase. Example 1 is given to compare the modified LMS-PPIC and the PLMS-PPIC in the case of balanced channels.

Example 1: Balanced channels: Consider the system model (3) in which M users synchronously send their bits to the receiver through their channels. It is assumed that each user's information consists of codes of length N . It is also assumed that the signal to noise ratio (SNR) is 0dB. In this example there is no power-unbalanced or channel loss is assumed. The step-size of the NLMS algorithm in modified LMS-PPIC method is $\mu = 0.1(1 - \sqrt{\frac{M-1}{M}})$ and the set of step-sizes of the parallel NLMS algorithms in modified PLMS-PPIC method are $\Theta = \{0.01, 0.05, 0.1, 0.2, \dots, 1\}(1 - \sqrt{\frac{M-1}{M}})$, i.e. $\mu_1 = 0.01(1 - \sqrt{\frac{M-1}{M}}), \dots, \mu_4 = 0.2(1 - \sqrt{\frac{M-1}{M}}), \dots, \mu_{12} = (1 - \sqrt{\frac{M-1}{M}})$. Figure 1 illustrates the bit error rate (BER) for the case of two stages and for $N = 64$ and $N = 256$. Simulations also show that there is no remarkable difference between results in two stage and three stage scenarios. Table I compares the average channel phase estimate of the first user in each stage and over 10 runs of modified LMS-PPIC and PLMS-PPIC, when the the number of users is $M = 15$.

Although LMS-PPIC and PLMS-PPIC, as well as their modified versions, are structured based on the assumption of no near-far problem (examples 2 and 3), these methods and

TABLE II
CHANNEL PHASE ESTIMATE OF THE FIRST USER (EXAMPLE 2)

$\phi_n = \frac{3\pi}{8}, M = 15$	N(Iteration)	Stage Number	NLMS	PNLMS
	64	s=2	$\hat{\phi}_m^s = \frac{2.45\pi}{8}$	$\hat{\phi}_m^s = \frac{2.36\pi}{8}$
		s=3	$\hat{\phi}_m^s = \frac{2.71\pi}{8}$	$\hat{\phi}_m^s = \frac{2.80\pi}{8}$
	256	s=2	$\hat{\phi}_m^s = \frac{3.09\pi}{8}$	$\hat{\phi}_m^s = \frac{2.86\pi}{8}$
		s=3	$\hat{\phi}_m^s = \frac{2.93\pi}{8}$	$\hat{\phi}_m^s = \frac{3.01\pi}{8}$

especially the second one have remarkable performance in the cases of unbalanced and/or time varying channels.

Example 2: Unbalanced channels: Consider example 1 with power unbalanced and/or channel loss in transmission system, i.e. the true model at stage s is

$$r(n) = \sum_{m=1}^M \beta_m w_m^s \alpha_m^{(s-1)} c_m(n) + v(n), \quad (17)$$

where $0 < \beta_m \leq 1$ for all $1 \leq m \leq M$. Both the LMS-PPIC and the PLMS-PPIC methods assume the model (3), and their estimations are based on observations $\{r(n), X^s(n)\}$, instead of $\{r(n), \mathbf{G}X^s(n)\}$, where the channel gain matrix is $\mathbf{G} = \text{diag}(\beta_1, \beta_2, \dots, \beta_m)$. In this case we repeat example 1. We randomly get each element of G from $[0, 0.3]$. Figure 2 illustrates the BER versus the number of users. Table II compares the channel phase estimate of the first user in each stage and over 10 runs of modified LMS-PPIC and modified PLMS-PPIC for $M = 15$.

Example 3: Time varying channels: Consider example 1 with time varying Rayleigh fading channels. In this case we assume the maximum Doppler shift of 40HZ, the three-tap frequency-selective channel with delay vector of $\{2 \times 10^{-6}, 2.5 \times 10^{-6}, 3 \times 10^{-6}\}$ sec and gain vector of $\{-5, -3, -10\}$ dB. Figure 3 shows the average BER over all users versus M and using two stages.

IV. CONCLUSION

In this paper, parallel interference cancellation using adaptive multistage structure and employing a set of NLMS algorithms with different step-sizes is proposed, when just the quarter of the channel phase of each user is known. In fact, the algorithm has been proposed for coherent transmission with full information on channel phases in [1]. This paper is a modification on the previously proposed algorithm. Simulation results show that the new method has a remarkable performance for different scenarios including Rayleigh fading channels even if the channel is unbalanced.

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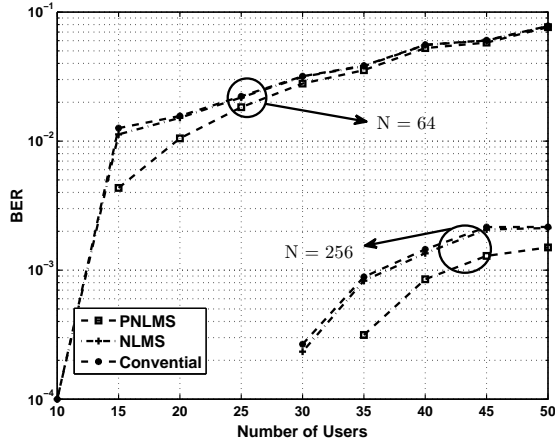


Fig. 1. The BER of the conventional, the modified LMS-PPIC and the modified PLMS-PPIC methods versus the system load in balanced channel, using two stages for $N = 64$ and $N = 256$.

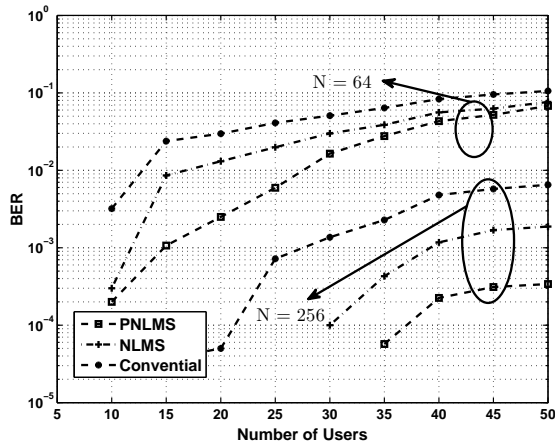


Fig. 2. The BER of the conventional, the modified LMS-PPIC and the modified PLMS-PPIC methods versus the system load in unbalanced channel, using two stages for $N = 64$ and $N = 256$.

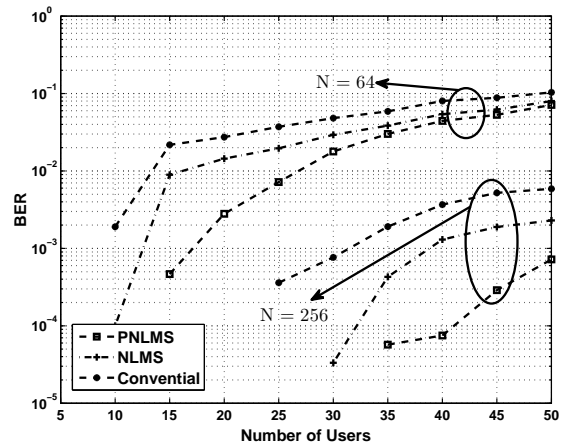


Fig. 3. The BER of the conventional, the modified LMS-PPIC and the modified PLMS-PPIC methods versus the system load in time varying Rayleigh fading channel, using two stages for $N = 64$ and $N = 256$.

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TABLE III
THE PROCEDURE OF THE MODIFIED PLMS-PPIC METHOD

Initial Values	for $m = 1, 2, \dots, M$	$\phi_m \in R_i, \quad i = 1, 2, 3, 4 \implies$ $\hat{\phi}_m^0 = \frac{(i-1)\pi + i\pi}{4}$ $\alpha_m^0 = \text{sign} \left\{ \text{real} \left\{ \sum_{n=1}^N r(n) e^{-j\hat{\phi}_m^0} p_m(n) \right\} \right\}$	
for $s = 1, 2, \dots, S$	PNLMS algorithm	for $n = 1, 2, \dots, N$	$W^s(0) = [w_1^s(0), \dots, w_M^s(0)]^T = [0, \dots, 0]^T$ $X^s(n) = [\alpha_1^{(s-1)} c_1(n), \alpha_2^{(s-1)} c_2(n), \dots, \alpha_M^{(s-1)} c_M(n)]^T$ $e(n) = r(n) - W^{s^T}(n-1)X^s(n)$ $Z(n) = \frac{X^{s*}(n)}{\ X^s(n)\ ^2} e(n)$ $\min = \infty, l = 1$
		for $k = 1, 2, \dots, L$	$W_k^s(n) = W^s(n-1) + \mu_k Z(n)$ if $\sum_{m=1}^M \ w_{m,k}^s(n) - 1\ < \min :$ $\min = \sum_{m=1}^M \ w_{m,k}^s(n) - 1\ $ $l = k$
			$W^s(n) = W_l^s(n)$
		for $m = 1, 2, \dots, M$	$i = 1, 2, 3, 4 \implies$ $\hat{\phi}_m^s = \angle w_m^s(N)$ if $\angle w_m^s(N), \phi_m \in R_i$ $\hat{\phi}_m^s = \angle w_m^s(N) + \pi$ if $\angle w_m^s(N) + \pi, \phi_m \in R_i$ $\hat{\phi}_m^s = \angle w_m^s(N) - \pi$ if $\angle w_m^s(N) - \pi, \phi_m \in R_i$ $\hat{\phi}_m^s = \frac{(i-1)\pi + i\pi}{4}$ if $\phi_m \in R_i, \angle w_m^s(N), \angle w_m^s(N) \pm \pi \notin R_i$
		for $m = 1, 2, \dots, M$	$q_m^s(n) = r(n) - \sum_{m'=1, m' \neq m}^M w_{m'}^s(N) \alpha_{m'}^{(s-1)} p_{m'}(n)$ $\alpha_m^s = \text{sign} \left\{ \text{real} \left\{ \sum_{n=1}^N q_m^s(n) e^{-j\hat{\phi}_m^s} p_m(n) \right\} \right\}$